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DAILY RESPONSE OF THE UPPER F REGION TO CHANGES IN UPPER ATMOSPHERIC TEMPERATURE AND GEOMAGNETIC ACTIVITY

S. CHANDRA

B. V. KRISHNAMURTHY

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NASA — GODDARD SPACE FLIGHT CENTER — GREENBELT, MARYLAND

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by

S. Chandra and B. V. Krishnamurthy*

Laboratory for Space Sciences
NASA-Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The day to day variations of the daytime F region electron density at four representative magnetic dip zones, namely 0-5, 25-30, 45-50 and 65-70, are investigated in relation to the other geophysical parameters such as the temperature of the neutral atmosphere, the daily sum of the planetary magnetic indices (ΣKp) and the 10.7 cm solar flux. For this purpose, the plasma frequencies at 1000 km (JFOS) and the critical frequencies (JFOF2) obtained from the Alouette I satellite and the neutral temperatures derived from the Explorer IX satellite drag data over a six month period from October 1962 to March 1963 are used. In general, it is found that the day to day variations of JFOS and JFOF2 in the daytime follow the corresponding variations of the neutral temperature and ΣKp. This trend is not evident with 10.7 cm flux. Correlation coefficients obtained between JFOS, JFOF2 vs temperature and vs ΣKp show a marked latitudinal dependence. Some of the implications of the results obtained in the present investigation are discussed.

*NAS-NRC Postdoctoral Resident Research Associate

INTRODUCTION

The effects of solar and geomagnetic activities on the bottomside F region parameters have been extensively studied by a number of workers [see for example Appleton and Piggott, 1955; Rastogi, 1962; Mariani, 1963; Becker, 1964]. Though the influence of these activities on ionization density at various levels on a long term basis is well known, their relationship on a day to day basis is, in general, not quite evident. Chandra and Rangaswamy (1966) using neutral temperature data derived from satellite drag, as a combined index of solar EUV radiation and geomagnetic activities showed that at Puerto Rico (dip 51°N), throughout the morning hours, electron density at fixed heights and maximum electron density of the F_2 region, in general, follow the same variations as the temperature. This relation could not be clearly established for other stations. With the availability of the vast amount of electron density data from the Alouette I satellite, it has now become possible to study this problem in the topside F region. Because of the extensive coverage from pole to pole, Alouette I provides an excellent opportunity for studying the latitudinal dependence of correlation between electron density and other geophysical parameters. The object of this paper is to report the results of such a study.

METHOD OF ANALYSIS

Alouette I has a nearly circular orbit at an altitude of about 1000 km and an orbital period of about 105 minutes. Because of the high orbital inclination of the satellite, it gives a good latitudinal coverage of the topside ionosphere in a relatively short time. The variations in ionization density over a given path are mainly due to variations in geomagnetic latitude and solar zenith angle χ. In the present investigation the ionospheric data was obtained from a series of reports entitled

"Alouette I Ionospheric Data Alosyn", published by Defence Research Board, Telecommunication Establishment, Canada. These reports publish among other things, the plasma frequency at the satellite altitude (JFOS) and the critical frequency (JFOF2) for each satellite pass as a function of dip and solar zenith angle. For each satellite pass, the JFOS and JFOF2 data are grouped into four representative magnetic dip zones, namely 0-5, 25-30, 45-50 and 65-70. All the values of JFOS and JFOF2 falling within a specified dip zone are averaged for north and south bound passes separately. The averaged values of JFOS and JFOF2 are taken to represent the ionization density at 1000 km and at the height of the F_2 region maximum, respectively. The corresponding value of zenith angle χ is likewise obtained by adopting a similar averaging procedure. Thus on each day two values of JFOS and JFOF2 corresponding to the north and south bound passes of the satellite are obtained for each dip zone considered.

The JFOS and JFOF2 data for each dip zone are then plotted against the corresponding days. Such a plot of JFOS and JFOF2 for the dip zone 45-50 for both north and south bound passes are shown in Figs. 1a and 1b respectively. The data plotted covers a period of six months from October 1962 to March 1963. The corresponding values of solar zenith angle are also plotted in these figures. The zenith angle of the sun is taken as a convenient solar parameter for this analysis instead of the local time since it includes the effect of diurnal and seasonal variation of the sun's position as has been pointed out by Chandra and Rangaswamy (1967). From these figures the large day to day fluctuations JFOS and JFOF2 superposed on the slow diurnal variation can be readily seen. These fluctuations are much more pronounced during the daytime ($\chi<100^{\circ}$) than during the nighttime ($\chi>100^{\circ}$). The diurnal behavior is particularly marked in the JFOF2 plot and so are the sunrise and sunset effects indicating a greater solar control at the height of the maximum than at 1000 km level.

CORRELATION WITH GEOPHYSICAL PARAMETERS

The day to day variations in JFOS and JFOF2 are now investigated in terms of their associations with the temperature of the neutral atmosphere, the daily sum of the planetary magnetic indices ΣKp and the 10.7 cm solar flux. For this purpose in accordance with the earlier observation that the changes in electron density at various levels are more marked in the daytime than in the nighttime, the data is divided into two parts: $\chi<100^{o}$ (corresponding to the daytime condition) and $\chi>100^{o}$ (corresponding to the nighttime condition). Both north and south bound passes are then combined in such a way as to give continuous coverage over the period from October 1962 to March 1963 for the two cases. Fig. 2 shows such a plot for $\chi<100^{o}$ for the dip zone 45-50^{o}. Plotted in this figure are also temperature, ΣKp and 10.7 cm solar flux ($S_{10.7}$) for comparison.

The temperature data used in figure 2 are the neutral temperatures derived [Roemer, 1966] from the drag data of Explorer IX satellite from the precisely reduced photographic observations. These temperatures are reduced to a standard nighttime minimum temperature (T_N) for each day. Thus T_N has been chosen, as an appropriate parameter to represent the day to day variations in the temperature of the upper atmosphere. Since our objective is to investigate the association, if any, between the day to day variations in the neutral temperature and those in the electron density in the topside F region, any conclusion drawn by using T_N as a parameter should be valid if it is assumed that the day to day variations in temperature throughout the day follow the corresponding variations in T_N.

From an examination of nighttime plots ($\chi>100^{o}$) it is found that there is no systematic correspondence between the variations of JFOS and JFOF2 with any of the three parameters ie. T_N, ΣKp and 10.7 cm flux. The daytime plots of JFOS and JFOF2, show in general good correspondence with T_N and ΣKp (as can be seen from Fig. 2 for the dip range 45-50). The day to day variations in the 10.7 cm flux are relatively small and it is not evident that they are the indicative of JFOS and JFOF2 variations.

RESULTS OF CORRELATION ANALYSIS

The comparison made in the preceding section is of course very qualitative. A quantitative estimate of the degree of association between the various parameters may be obtained by subjecting the data to correlation analysis. However, in view of the large diurnal and seasonal variations superposed on the data it is necessary to minimize their effects for any meaningful correlation on a day to day basis. This is particularly true for electron density data which has a component of about two months (as the data corresponds to χ<100) resulting from the diurnal variation. Thus the correlation between electron density data obtained from Alouette I satellite and other parameters like T_N, ΣKp and $S_{10.7}$ may give rise to spurious results unless the long term components are removed from their respective data. This can be done by using a mathematical filter based on running averages. This filter is very useful in view of its computational simplicity. The frequency response of such a filter is given by (Holloway, 1958).

$$R(f) = \frac{\sin \pi fT}{\pi fT}$$

where R(f) is the amplitude response for the frequency f over the running average period T. It can be seen from the above relation that R(f)>93.5% for frequencies < $\frac{1}{5T}$, the response being zero at f = $\frac{1}{T}$. Thus a series obtained by taking running averages over a period of 5 days will retain essentially all the long term components of about 25 days period and above. Likewise, the difference between the original series and the series obtained by running averages will be practically free from long term components and will essentially contain the short term components. The difference series are thus useful for quantitative investigation of the short-term variations.

The difference time series based on 5-day running averages are obtained from the original data for all the parameters under consideration. From these series, the cross-correlation between the various parameters (JFOS, JFOF2, T_N, ΣKp and $S_{10.7}$) are obtained for all the latitude zones giving a time difference of -5 to +5 days in steps of 1 day. The total number of observations used in the computations of correlation coefficients are about 150. The results of these computations are shown in Figs. 3, 4 and 5.

Considering first the correlation coefficients of JFOS and JFOF2 with ΣKp [$r_{JFOS,\Sigma Kp}$ and $r_{JFOF2,\Sigma Kp}$], it is seen from Fig. 3 that the maximum coefficient is positive and in general peaks around 0 day time difference. The values of $r_{JFOS,\Sigma Kp}$ are significant (at 1% level) only for 45-50^{o} and 65^{o}-70^{o} dip range though their systematic increase with dip angle is quite evident. The sharp fall of $r_{JFOS,\Sigma Kp}$ on either side of the peak is indicative of the presence of short term components in the filtered series of the two parameters. The cross correlation between JFOF2 and ΣKp shows a significant peak only at the dip zones 0-5 and 45-50^{o}.

The correlation coefficients of JFOS and JFOF2 with temperature (Fig. 4) show essentially the same features as those with ΣKp except that the peak occurs, in general, around -1 day time difference. As the time resolution of the data used here is about 1 day it is difficult to attach any real significance to such a time difference.

The correlation coefficients of JFOS and JFOF2 with 10.7 cm flux are not significant in general at all the four dip zones as is indicated in Fig. 5.

The conclusions of this section are not basically altered by repeating the computation with 7, and 9 days running mean differences. Increasing the averaging interval admits the lower frequencies in the filtered series. This results in reducing the sharpness of the correlation peaks.

SUMMARY AND CONCLUSIONS

The results of the correlation analysis based on short term variations in various parameters described in the previous section may be summarized as follows:

1. Electron density at 1000 km shows a significant positive correlation with ΣKp and T_N at the dip zones 45-50 and 65-70, the correlation coefficient being higher at 65-70 than that at 45-50. At the other dip zones considered, namely 0-5 and 25-30 the correlation is not significant though positive.
2. Electron density at the height of F_2 region maximum shows significant correlation with ΣKp and T_N only at the dip zones 0-5 and 45-50, the correlation being positive.
3. Electron density at both 1000 km and the F_2 region maximum shows no significant correlation with the 10.7 cm solar flux.

If the atmospheric temperature is one of the main factors controlling the distribution of F_2 ionization as was indicated from the study of Chandra and Rangaswamy (1966), the lack of correlation between decimeter flux and electron density at various levels may, at first, appear somewhat perplexing. This is particularly so, since the former is widely used as an index of atmospheric temperature [Jacchia, 1963]. It should be recognized, however, that the results reported in this paper are based on the analysis of filtered series which are free from long-term components. In a recent communication [Chandra and Krishnamurthy, 1967] using a filtering technique similar to the one described in this paper, we have shown that the long term variations having periods of 27 days and above in the upper atmospheric temperature are well correlated with those in the decimeter flux. The short-term variations in temperature, such as the day-to-day variations, however, are strongly correlated with geomagnetic fluctuations as represented by ΣKp. The correlation between temperature and decimeter flux on a short-term basis is almost negligible. Thus, the lack of correlation between electron density and decimeter flux on a short term basis is to be expected. Unfortunately, electron density data from Alouette I satellite does not permit us to study the long term variations in relation to other parameters like T_N, ΣKp and $S_{10.7}$ unless the diurnal variation superposed on the electron density data is properly accounted for.

From the present analysis, it is difficult to distinguish between ΣKp and temperature T_N as the primary parameter influencing the day to day changes in electron density. Both the parameters do not have any latitudinal characteristics and hence the latitudinal variation of correlation coefficients with either of these parameters is primarily an indication of latitudinal variation of day to day changes in electron density.

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FIGURE CAPTIONS

FIGURE 1a - Daily plots of JFOS and solar zenith angle χ for the dip zone 45^{o}-50^{o}.

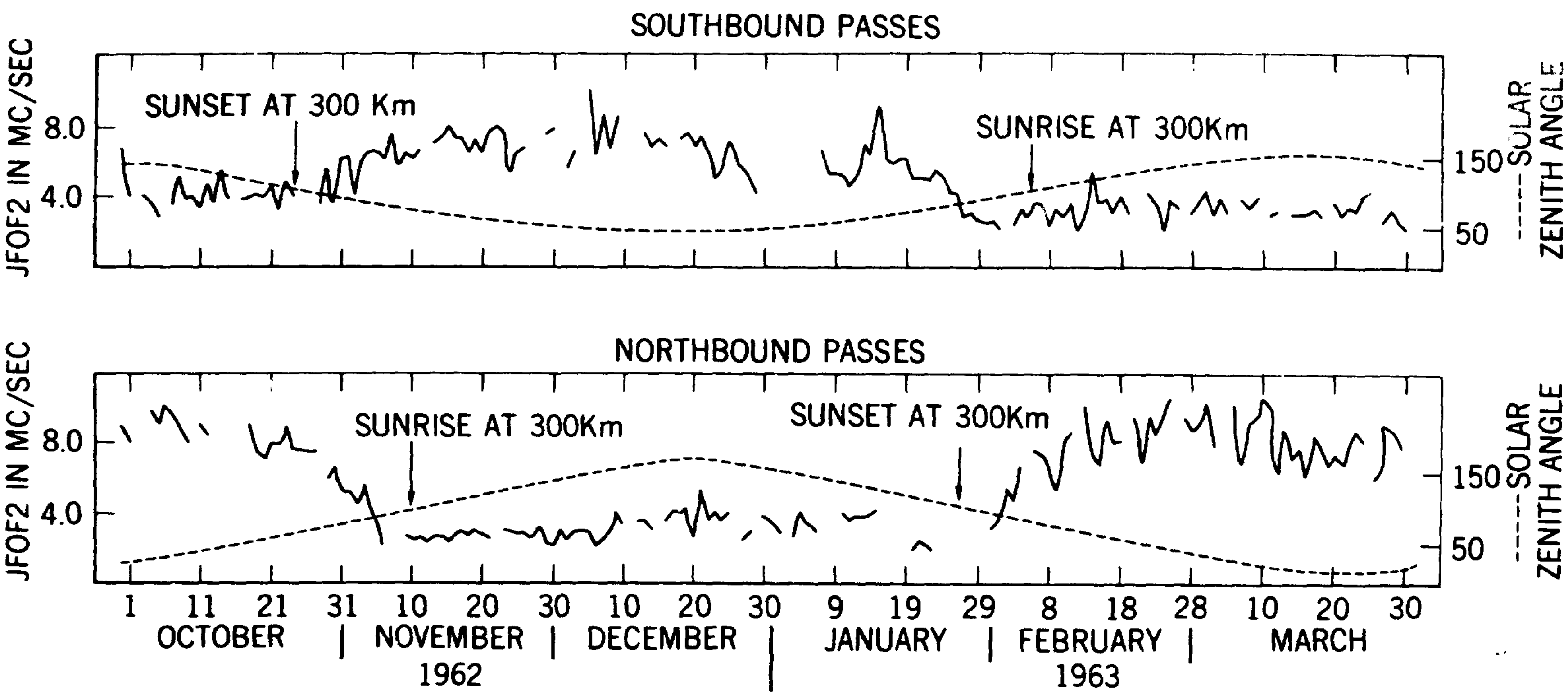
FIGURE 1b - Daily plots of JFOF2 and solar zenith angle χ for the dip zone 45^{o}-50^{o}.

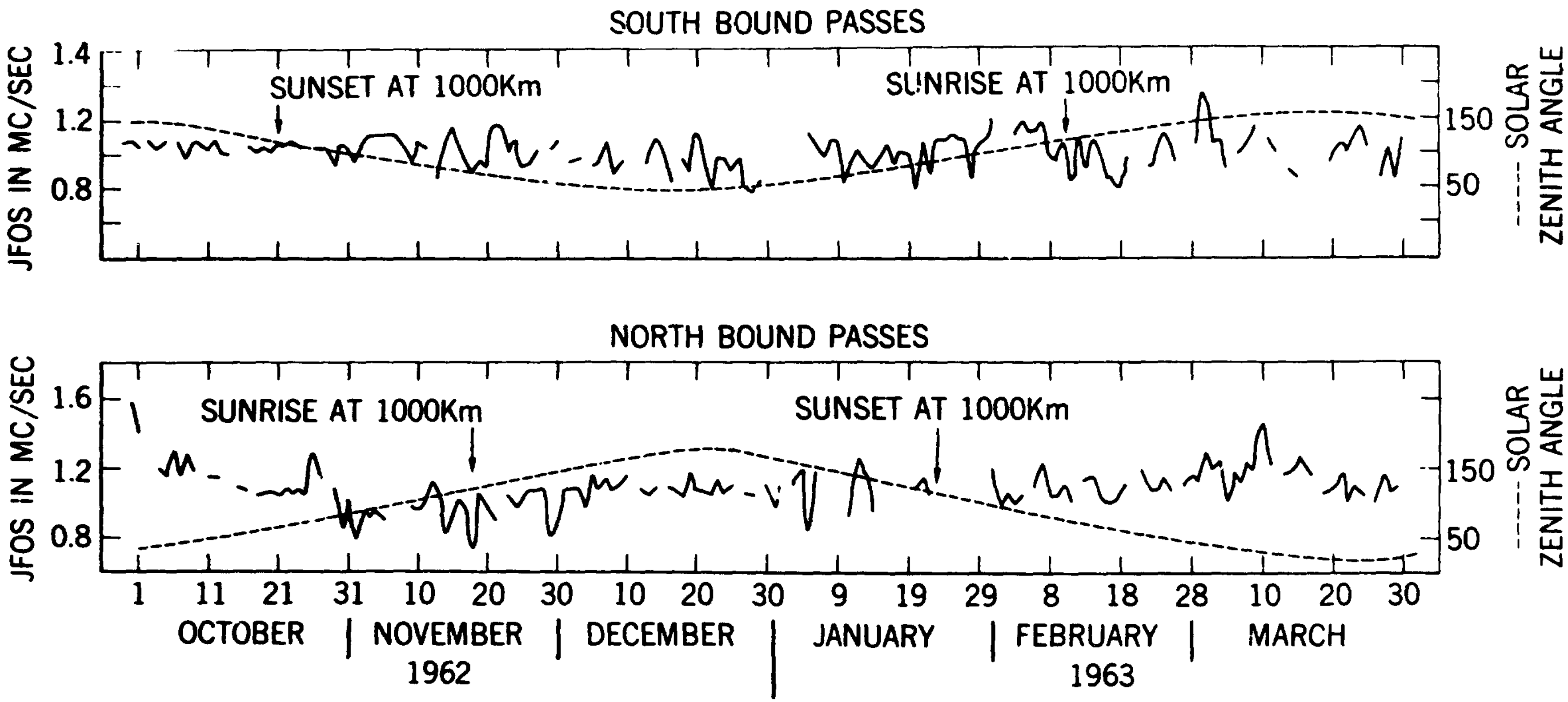
FIGURE 2 - Temporal variation of JFOS and JFOF2 (for $\chi<100^{o}$) for the dip zone 45^{o}-50^{o} and nighttime global minimum temperature T_N, daily sum of the planetary magnetic indices ΣKp and 10.7 cm solar flux.

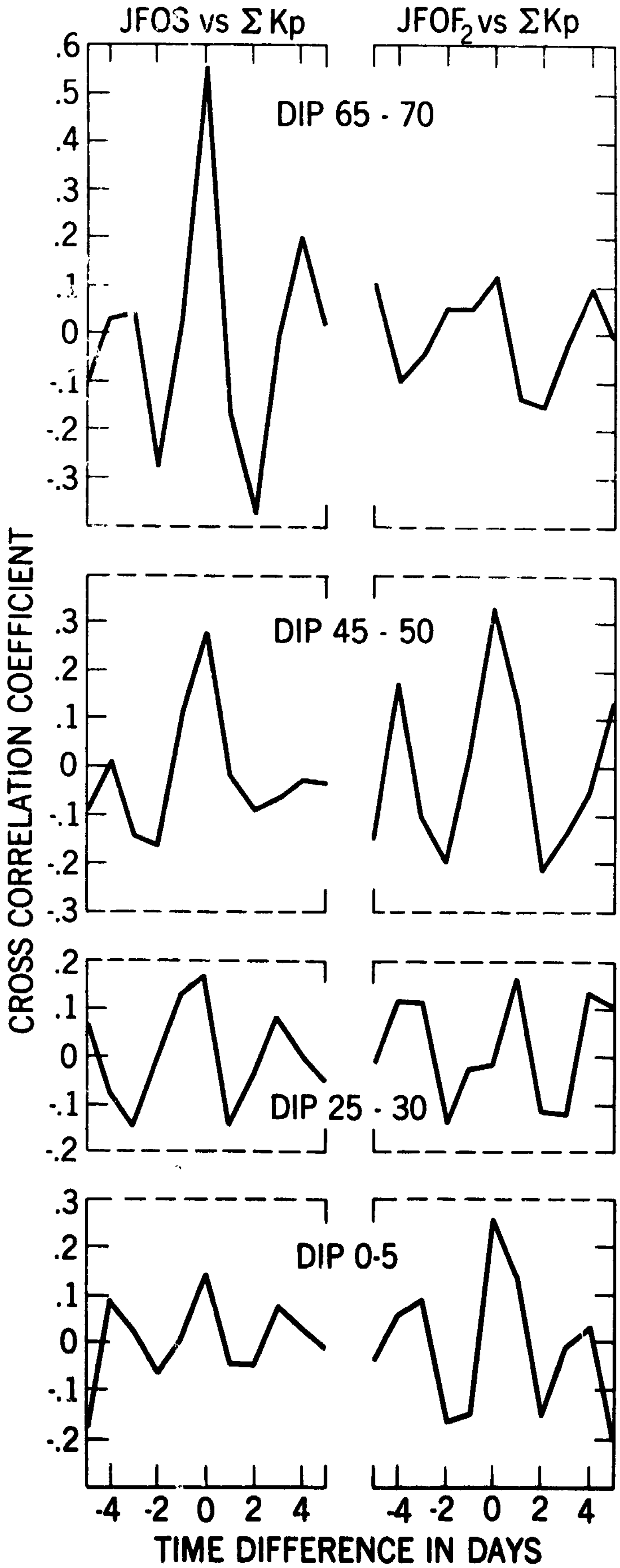
FIGURE 3 - Cross correlation of JFOS and JFOF2 with ΣKp. Correlation coefficients above .23 are significant at 1% level of significance.

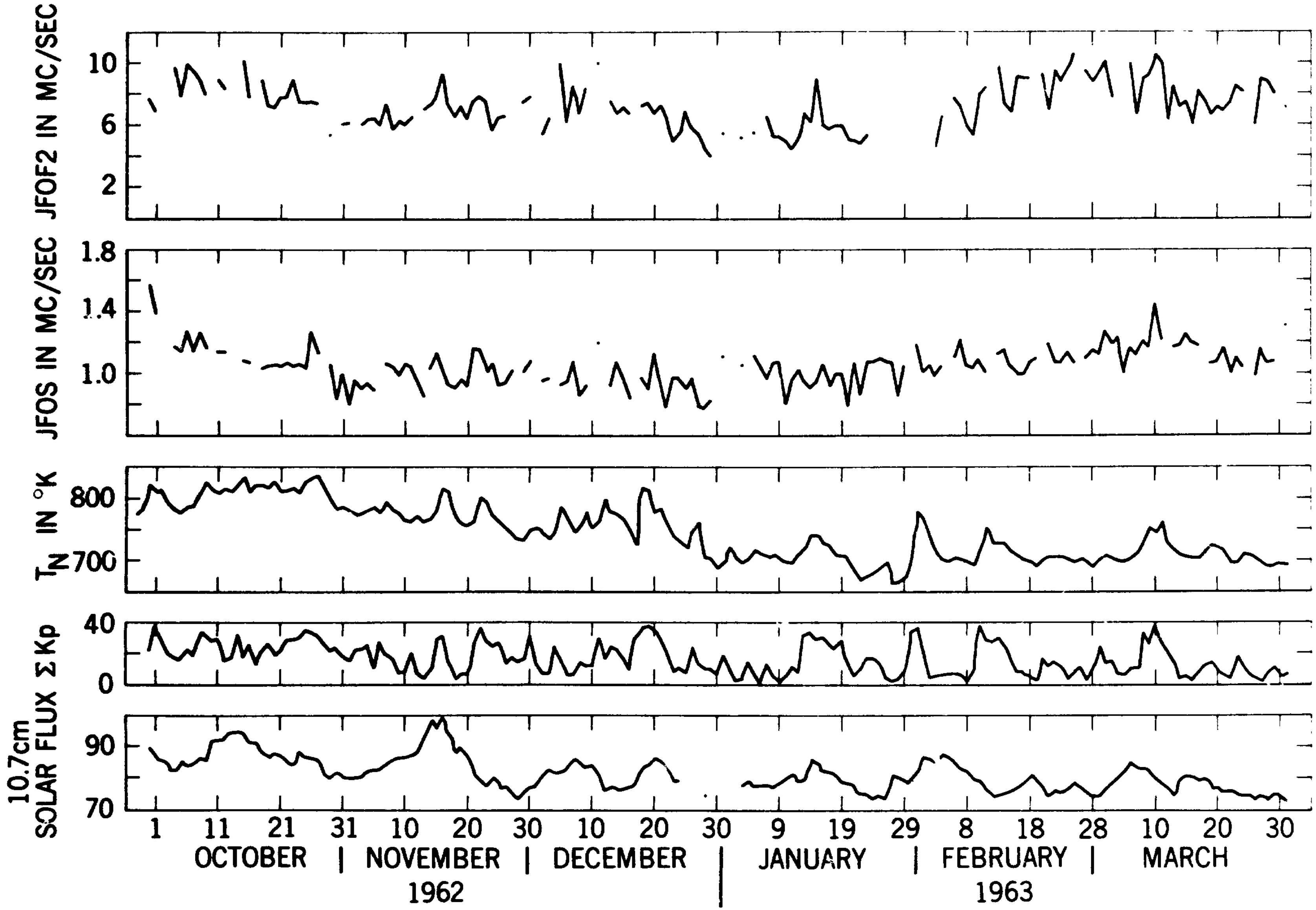
FIGURE 4 - Cross correlation of JFOS and JFOF2 with temperature T_N. Correlation coefficients above .23 are significant at 1% level of significance.

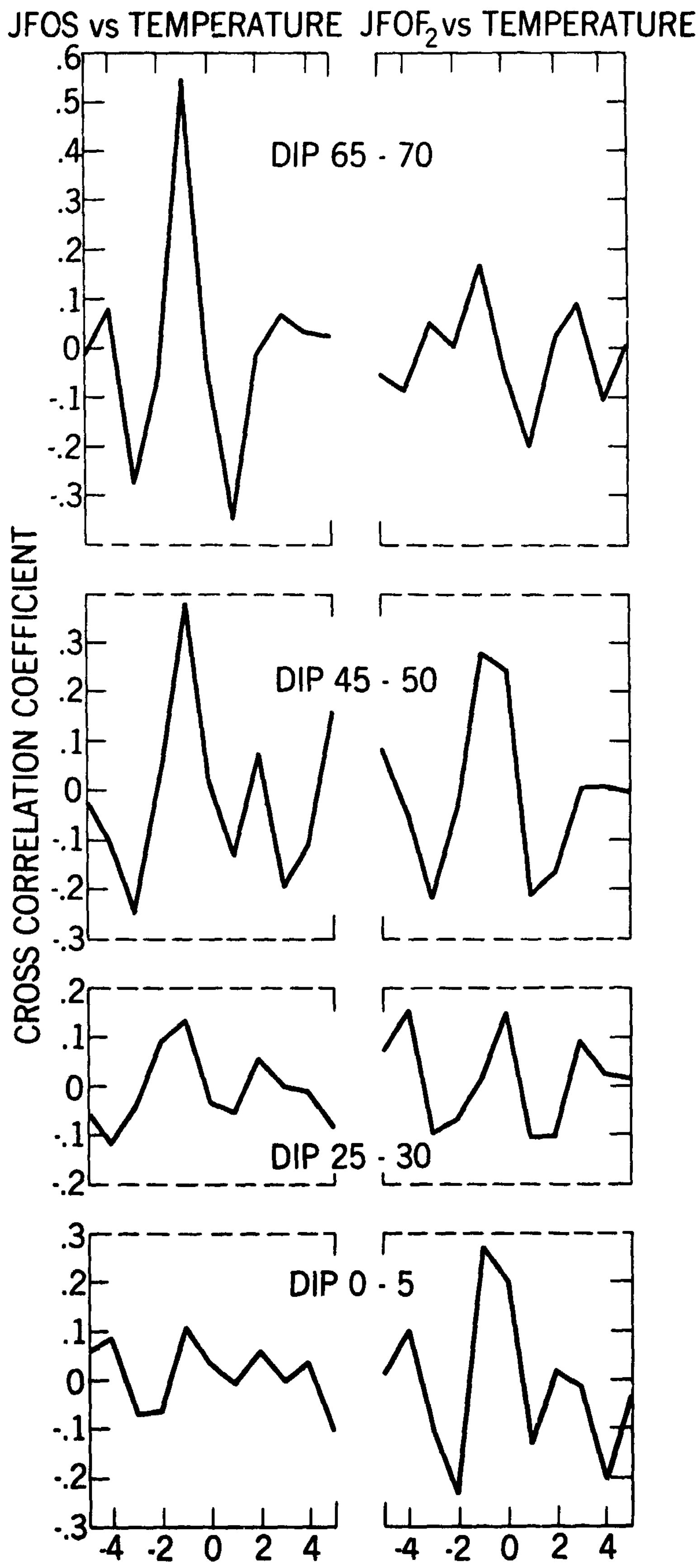
FIGURE 5 - Cross correlation of JFOS and JFOF2 with 10.7 cm solar flux. Correlation coefficients above .23 are significant at 1% level of significance.


SOUTHBOUND PASSES
SUNSET AT 300 Km
SUNRISE AT 300Km
JFOF2 IN MC/SEC
8.0
4.0
150
50
----SOLAR ZENITH ANGLE
NORTHBOUND PASSES
SUNRISE AT 300Km
SUNSET AT 300Km
JFOF2 IN MC/SEC
8.0
4.0
150
50
----SOLAR ZENITH ANGLE
1 11 21 31 10 20 30 10 20 30 9 19 29 8 18 28 10 20 30
OCTOBER
NOVEMBER
1962
DECEMBER
JANUARY
FEBRUARY
1963
MARCH

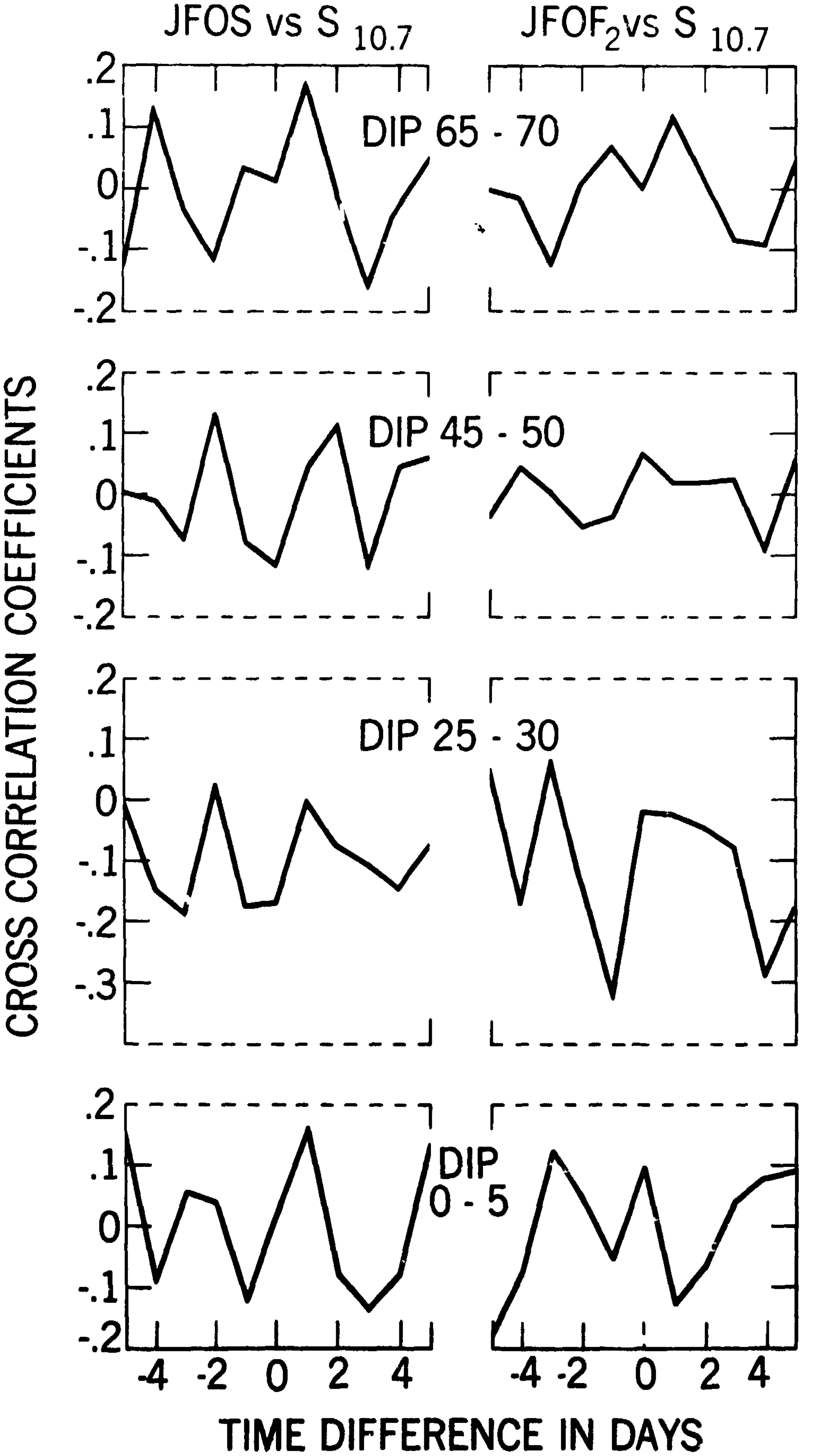

SOUTH BOUND PASSES
SUNSET AT 1000Km
SUNRISE AT 1000Km
JFOS IN MC/SEC
1.4
1.2
0.8
150
50
---- SOLAR ZENITH ANGLE
NORTH BOUND PASSES
SUNRISE AT 1000Km
SUNSET AT 1000Km
JFOS IN MC/SEC
1.6
1.2
0.8
150
50
---- SOLAR ZENITH ANGLE
1 11 21 31 10 20 30 10 20 30 9 19 29 8 18 28 10 20 30
OCTOBER
NOVEMBER
1962
DECEMBER
JANUARY
FEBRUARY
1963
MARCH


JFOS vs ΣKp
JFOF2 vs ΣKp
DIP 65 - 70
DIP 45 - 50
DIP 25 - 30
DIP 0-5
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
CROSS CORRELATION COEFFICIENT
-4 -2 0 2 4
TIME DIFFERENCE IN DAYS


JFOF2 IN MC/SEC
10
6
2
JFOS IN MC/SEC
1.8
1.4
1.0
T_N IN °K
800
700
ΣKp
40
0
10.7cm SOLAR FLUX
90
70
1
11
21
31
10
20
30
10
20
30
9
19
29
8
18
28
10
20
30
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
1962
1963



JFOS vs TEMPERATURE
JFOF2 vs TEMPERATURE
DIP 65 - 70
DIP 45 - 50
DIP 25 - 30
DIP 0 - 5
CROSS CORRELATION COEFFICIENT
TIME DIFFERENCE IN DAYS
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-4
-2
0
2
4



JFOS vs S 10.7
JFOF2 vs S 10.7
DIP 65 - 70
DIP 45 - 50
DIP 25 - 30
DIP 0 - 5
CROSS CORRELATION COEFFICIENTS
.2
.1
0
-.1
-.2
-.3
-4 -2 0 2 4
TIME DIFFERENCE IN DAYS